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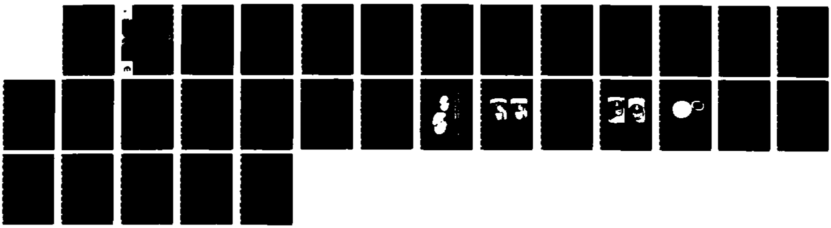

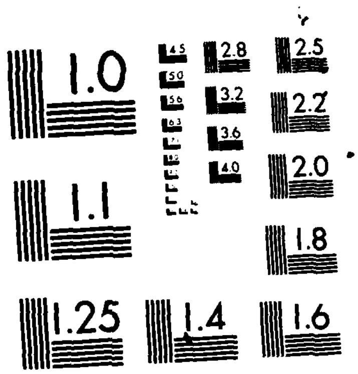
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US Army Corps of Engineers

AD-A172 948

INSTRUCTION REPORT SL-86-1

(2)

PROCEDURE FOR ASSEMBLING WES COLUMN-BASED SOIL STRESS GAGES

by

Denis D. Rickman, Howard G. White

Structures Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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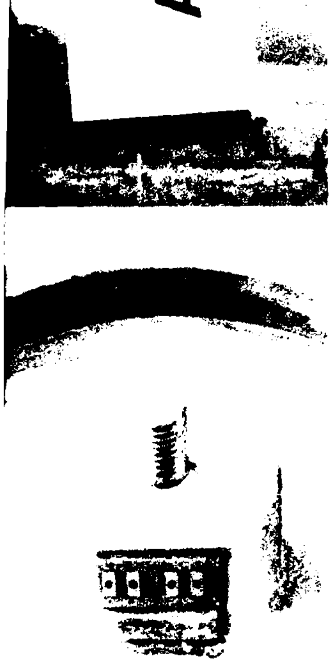

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes the present procedure used in the fabrication of WES column-based soil stress gages along with a complete set of machine drawings. The gage is capable of both static and dynamic stress measurements up to 50 ksi in various types of soils. It has been laboratory- and field-evaluated in several soil types, and is being used routinely for soil stress measurement by the Waterways Experiment Station. There is no known commercially available counterpart.

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PREFACE

This report was prepared as part of a research effort authorized and funded jointly by the Office, Chief of Engineers (OCE Task AT22/BO/006), the Defense Nuclear Agency (DNA Subtask Q93QMXJI, Work Unit 00003) and the US Air Force Ballistic Missile Office (BMO, MIPR 85-04009; D-16) during the period October 1983 through September 1985.

This study was performed by Mr. C. R. Welch (Program Manager), Mr. H. G. White, and Mr. C. D. Little, Jr., of the Explosion Effects Division (EED), Structures Laboratory, Waterways Experiment Station (WES). Also participating were Mr. F. P. Leake and Mr. W. B. Peterson of the Instrumentation Services Division, WES. This report was written by Mr. D. D. Rickman, EED, and Mr. White.

During the period of this research, Mr. J. D. Day was Chief, EED and Mr. Bryant Mather was Chief of the Structures Laboratory. The previous Director of WES was COL Allen F. Grum, USA. The present Commander and Director is COL Dwayne G. Lee. Technical Director is Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENTS

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	25.4	millimetres
pounds (force)	4.448222	newtons
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	6.894757	kilopascals

PROCEDURE FOR ASSEMBLING WES COLUMN-BASED SOIL STRESS GAGES

PART I: INTRODUCTION

Background

1. Design of underground protective structures to survive nuclear attack requires the knowledge of blast-induced soil reactions, including particle motions and stress. Particle velocity and acceleration and lower levels of soil stress (up to 10 ksi*) can be measured with proven devices. The measurement of soil stress up to the 50 ksi level is much more difficult. Some major problems involved with measurement of stress in soils are discussed below.

2. Inclusion of a gage in a soil medium disrupts the stress field and induces either stress concentrations or reliefs, depending on gage stiffness. Such stress-transfer phenomena can seriously affect gage reliability. A very stiff gage with a diameter-to-thickness ratio greater than five and a diameter-to-deflection ratio greater that 2000 will over-indicate by a relatively constant amount which is independent of the medium. These factors, along with gage-medium density matching, form the basis for stress gage design.** Measurement of soil stress in the 50 ksi range causes additional difficulties, such as plastic behavior of gaged surfaces (resulting in nonlinearity and hysteresis effects) and survivability problems for internal strain gages and wiring.

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*A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.
**U.S. Army Engineer Waterways Experiment Station, CE, Procedure For Assembling SE-Type Soil Stress Gages, Instruction Report No. 8, J. K. Ingram (Vicksburg, MS, March 1967).

3. Because of the need for a reliable gage to measure very high dynamic soil stresses in current explosive test programs, the task of developing a suitable gage was undertaken by the Waterways Experiment Station (WES) in early 1983. This effort resulted in the development of the column-based soil stress (CBS) gage. The CBS gage has been tested in numerous laboratory and field tests, and has proven capable of reliably measuring dynamic stresses as high as 50 ksi.

Purpose and Scope of Report

4. The purpose of this report is to describe the techniques required to assemble the WES CBS gage. A summary of the major technical specifications and a detailed description of the fabrication procedure is included.

PART II: THE WES COLUMN-BASED SOIL STRESS GAGE

General Gage Information

5. The design of the WES CBS gage is based on classical load-cell geometry, i. e., the elastic compression of a column. Detailed machine drawings of this gage design are provided in Appendix A. The gage has been designed to respond in a linear, elastic manner to loads in excess of 50 ksi. This was accomplished by making the gage very stiff and removing as little as possible of the interior to accommodate the sensing elements and wiring.* The transducer consists of two pieces: a massive body and a small cap section which includes the strain-gaged column sensing element.* The two pieces are bolted together to provide intimate contact, while a small annular void is left around the column (see Figure 1). Mating surfaces are lapped to ensure uniform contact between the two pieces. Major gage characteristics are listed in Table 1.

Gage Body

6. The gage body consists of a two-piece type 4340 steel housing which is bolted together. The larger bottom section contains the cable feed-through and cable protection fitting, while the smaller top section consists of the central load column and an annular flange (see Figure 2). The load column is initially a cylindrical protrusion 0.800 in. in diameter and 0.500 in. high. The rounded sides are milled to provide four flat surfaces: two horizontal gage flats 0.400 in. x 0.500 in. located 180° apart, and two vertical gage flats 0.217 in. x 0.500 in. located 180° apart from each other and 90° apart from the horizontal gage flats. A threaded 10-32 stud emanates from the center of the column. Eight holes are drilled at equal distances in the bottom housing section and counter sunk for using 10-32 high strength

*U.S. Army Engineer Waterways Experiment Station, CE, Design and Field Experience With the WES 10 K Bar Airblast and Soil Stress Gage, Charles E. Joachim and Charles R. Welch (Vicksburg, MS, October 1984).

socket head cap screws, while corresponding holes are drilled and tapped in the top section. A hole is also drilled at the center of the bottom section to allow for the threaded 10-32 stud emanating from the center of the load column. This hole is countersunk for a 10-32 brass nut.

7. After machining to the specifications of Appendix A, the steel is given the following heat treatment: normalized at 1600°F, reheated to 1475°F, oil quenched, and tempered at 750°F. This procedure gives an approximate Rockwell C hardness of 42 and a yield stress of 200 ksi. After heat treatment, the pieces are thoroughly sand blasted to remove any scale or foreign matter that may have formed. Finally, the mating surfaces are lapped using a grade E lapping compound in order to ensure uniform contact.

Sensing Elements

8. Semiconductor strain gages were selected as sensors due to their high output sensitivity. Kulite S/UDP-350-160 semiconductor strain gages were chosen because of their physical size and configuration. The strain gage specifications are listed in Table 2.

9. Four strain gages are bonded to the load column in the top section of the soil stress gage housing. Strain gages are positioned horizontally on the larger gage flats for Poisson compensation, and vertically on the smaller flats for primary sensing (see Figures 3a and 3b). The strain gages are wired in a full bridge configuration. An excitation current of 10 mA is typically used and bridge excitation of approximately 5 V is recommended. Bridge excitation should not exceed 20 V.

Strain Gage Attachment

10. The strain gages are bonded to the gage flats of the load column as shown in Figures 3a and 3b. Micromeasurements M-Bond AE-15 epoxy is used to bond the elements and terminal strip to the base metal.

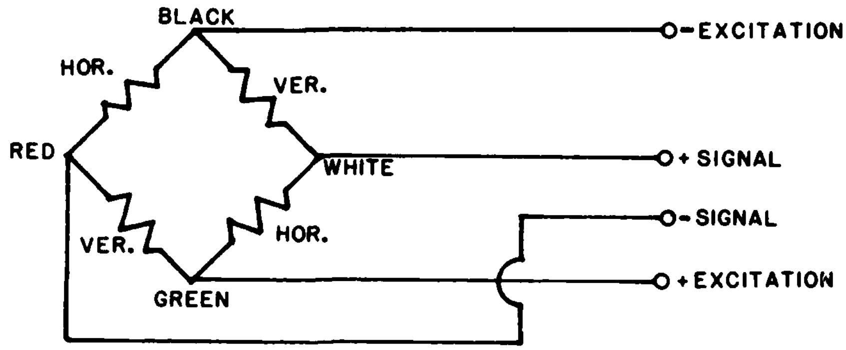
PART III: PRE-ASSEMBLY PROCEDURE

11. Prior to assembly of the CBS gage, the following steps should be performed. The gage housing components should be cleaned with acetone to remove any steel bluing ink and then thoroughly degreased with an appropriate solvent (Freon TF, etc). Any degreasing should be done with clean solvents and the use of a "one way" container, such as the aerosol can, is advisable. All gage flats should then be polished with 320-grit silicon carbide paper in order to provide smooth surfaces which can be properly cleaned. Cleaning should be done using a conditioning agent (such as M-Prep Conditioner A). After cleaning, the flats should be lightly resanded with 320-grit paper to ensure proper bonding of the epoxy to the column and then surface treated according to the instructions in Appendix B.

PART IV: ASSEMBLY PROCEDURE

12. The following step-by-step procedure should be used to assemble the CBS gage. It is important that all parts be handled with soft lintless gloves for all operations after surface treatment. Assembly operations should be conducted in a filtered, humidity controlled, air conditioned environment.

- a. Measure unbonded strain gage resistances and identify gages in packet. Record on data sheet similar to that shown in Figure 4.
- b. Glue one strain gage horizontally on each of the large flats (also place a terminal strip on one of these flats) and one vertical strain gage on each of the smaller flats, following the instructions in Appendix B. See Figures 3a and 3b.
- c. Oven-cure the AE-15 epoxy for a minimum of one hour at 175°F.
- d. After oven-curing, remove positioning tape and use aerosol Freon TF to remove dust and residue.
- e. Apply AE-10 epoxy to all exposed areas on the sides of the column (do not apply to gages or terminal strip). Let epoxy cure according to specifications. Do not cure at high temperature in order to avoid damage to solder connections and epoxy already in place. This process should ensure that all wires will be insulated from the column.
- f. Measure and record bonded gage resistances.
- g. Apply solder beads to gage tabs and terminal strip using a pulse dot solder system to minimize mass of solder on gage tabs. Use No. 4 or 5 beads. Both the pulse dot soldering system and the solder beads are available from Circon Industries.
- h. Connect the strain gages as a full Wheatstone bridge using 36 gage solderease wire. The WES color code hook-up is shown below.



Measure individual gage resistances and record junction resistances. Also check resistance to ground. Expected resistance values are:

Black-Green = Red-White = 380-410 ohms

Individual strain gages should read close to their original values. All points to ground should exceed 50 Mohms.

i. Bond solderease wire to the column using a minimal amount of M-Bond AE-10 epoxy. Be sure to cover the wires and solder connections (the gages themselves may be coated also) as shown in Figures 5a and 5b. Be sure not to cover the terminal strip tabs. Let epoxy cure at ambient temperature, then check resistances. At this point the bridge completion wires and solder connections should be encapsulated in AE-10 epoxy.

j. Connect a durable, insulated, shielded, 1/8 in. diameter four-conductor cable (such as W. L. Gore GWA8022 Rev. A) at the terminal strip using minimal solder. The cable jacket should be pulled so that the cable shield is approximately 1/8 in. inside the jacket, and the lead wires should be approximately 1/4 in. beyond the jacket. Keep the lead wires stripped back a minimal amount (just enough to allow a good solder connection). Cable length should be 10 ft. Cover solder joints with AE-10 epoxy and cure at ambient temperature. Check resistances at end of lead cable.

k. Place O-ring in housing base.

l. Place one piece of teflon (0.003 in. thick x 0.800 in. diameter) at base of column. A center hole will be required for the 10-32 stud which protrudes from the column base (see Figures 5a and 5b).

m. Route cable through base section cable exit and then place sensing element into the base section so that terminal strip is nearest cable exit.

n. Rotate as little as possible to align screw holes.

o. Connect the gage housing sections using 10-32 x 5/8 in. high strength socket head cap screws. Torque to 85-90 in.-lb.

p. Thread a 10-32 brass nut on the center stud. Torque to 40-45 in.-lb, taking care not to over torque.

q. Flatten modeling clay over cap screw heads and brass nut, leaving room for a 1/16 in. layer of 5-minute epoxy or equivalent. Apply epoxy and allow to cure. Epoxy should be flush with bottom surface of gage body.

r. Orient gage so that the cable exit hole is pointing upward. Fill cable exit hole with AE-10 epoxy to top of angled counter bore. Make sure the bottom of the cable exit hole is sealed to prevent epoxy from seeping into the gage interior. Allow epoxy to cure.

s. Measure and record all resistances, including resistances to ground. Finished product should resemble Figure 6.

Table 1

MAJOR CHARACTERISTICS OF THE WES CBS GAGE.

Overall dimensions:	
Diameter	5.000 in.
Thickness	1.050 in.
Column dimensions:	
Diameter	0.800 in.
Horizontal gage flat	0.400 in. x 0.500 in.
Vertical gage flat	0.217 in. x 0.500 in.
Output	0.0048 mV/V/psi
Linearity	5.9% full scale
Hysteresis	4.9% full scale
Temperature range	Below 30° to 150° F
Recommended excitation	5 V
Maximum excitation	20 V
Apparent strain sensitivity	2 to 5 in./in./psi
Natural frequency	199 kHz
Effective frequency response	40 kHz

Table 2

STRAIN GAGE SPECIFICATIONS FOR THE WES CBS GAGE.

Temperature range	-320°F to +350°F
Active gage length	0.12 in.
Nominal resistance	350 ohms
Gage factor	115 ±5% @ 75°F
Sensing material	P-type semiconductor (silicon)
Leads	Solder tab terminals incorporated into gage matrix, both leads at same end of gage
Minimum radius of curvature	0.250 in.
Overall dimensions:	
Width	0.160 in.
Length	0.200 in.
Backing material	epoxy/glass

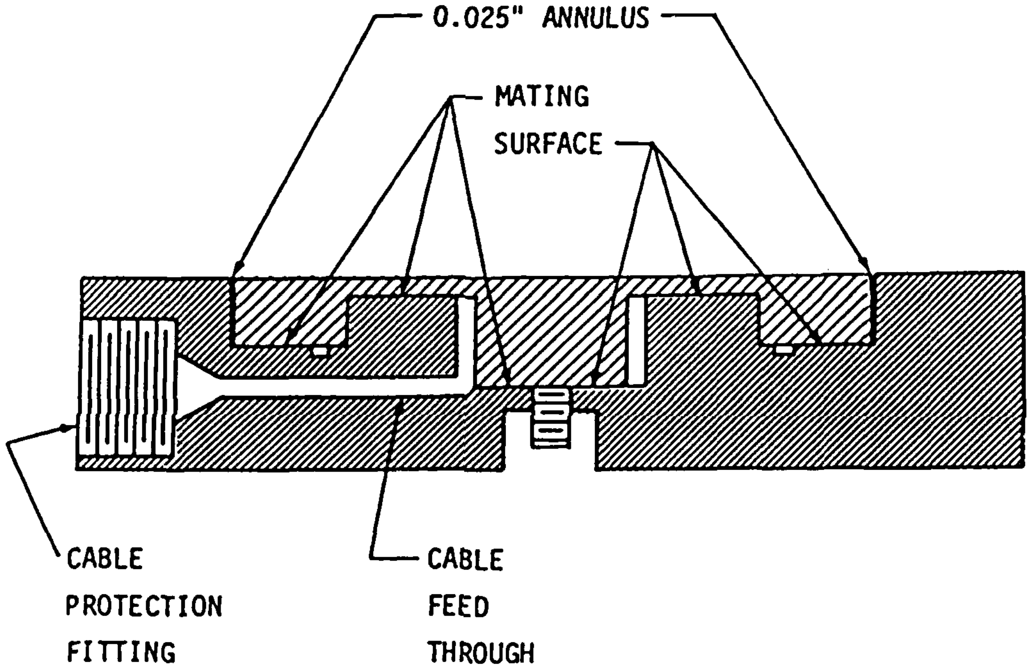


Figure 1. Schematic cross section of the WES column-based soil stress (CBS) gage

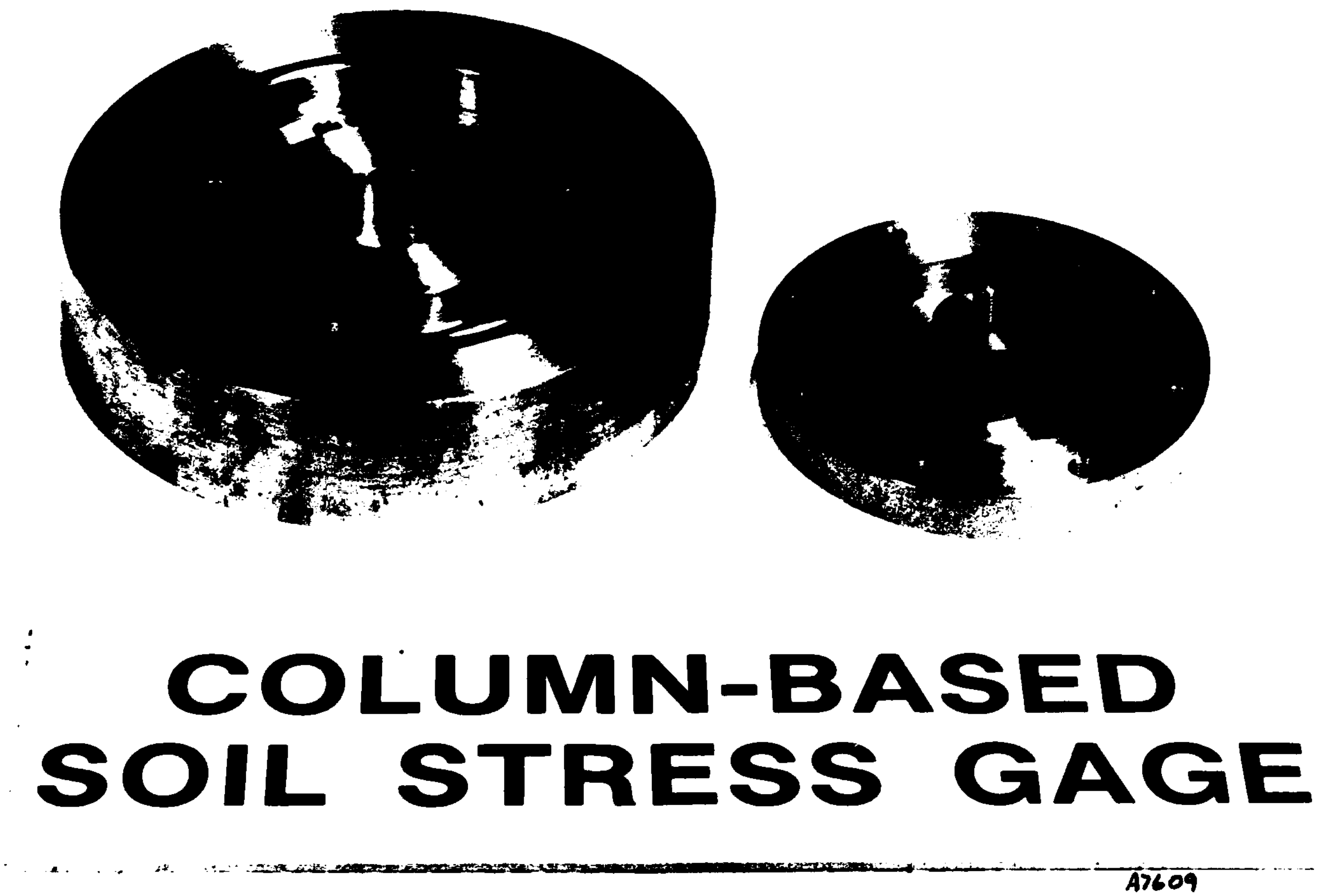


Figure 2. WES CBS gage housing components

a. Vertical gage

b. Horizontal gage, shown with terminal strip

Figure 3. Strain gage positions

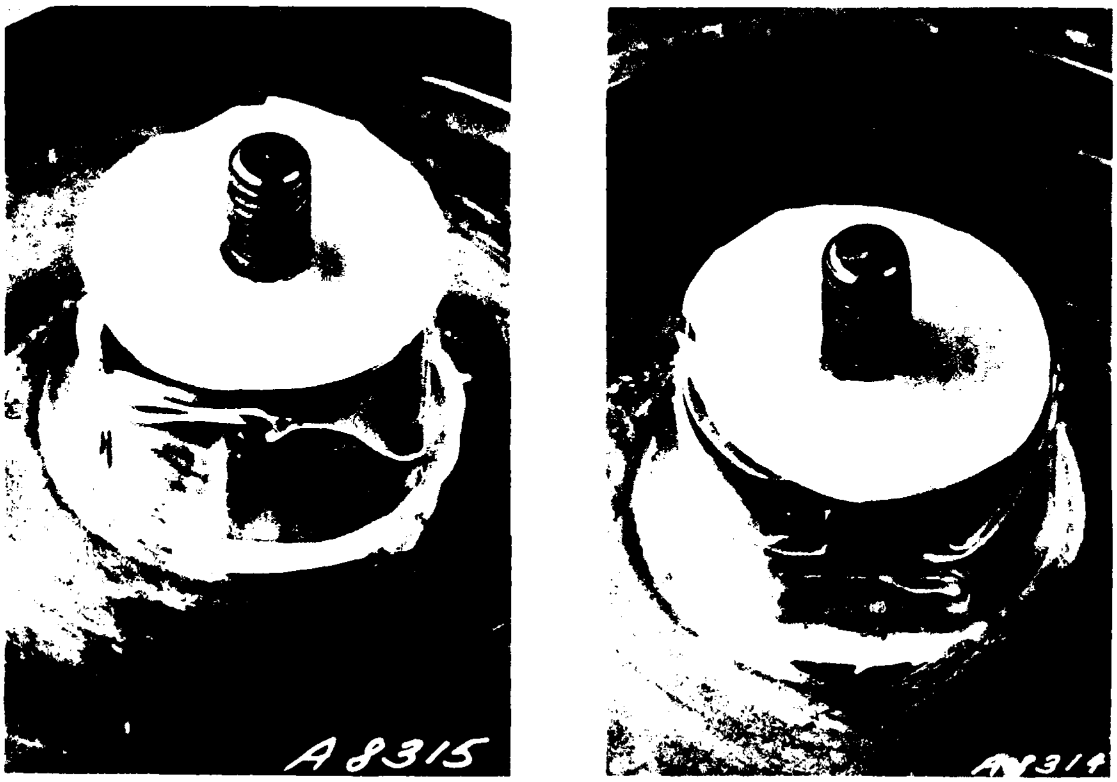
Table

Electrical Assembly Data

Transducer	Mfg Strain Gage Data			Measured Unbonded Gage Resistance, Ω					Measured Bonded Gage Resistance, Ω					Measured Junction (Half-Bridge) Resistances, Ω					Bridge Balance SR Indicator			
	Lot		GF	Gage No.					Gage No.					Junction					$\mu\epsilon$			
S/N	No.	R±1%	+2%	1	2	3	4	Date	1	2	3	4	Date	AB*	BC	CD	DA	Date	a	b	c**	Date
									ab**	ab	ab	ab		ab	ab	ab	ab					

* AB, etc, bridge junctions
** a, before assembly; b, after assembly; c, completed gage (with epoxy rim).

Figure 4. Sample tabulation form



a. Vertical gage

b. Horizontal gage, shown with terminal strip

Figure 5. View of sensing column with completed bridge. Shown after application of epoxy cover and positioning of Teflon wafer.

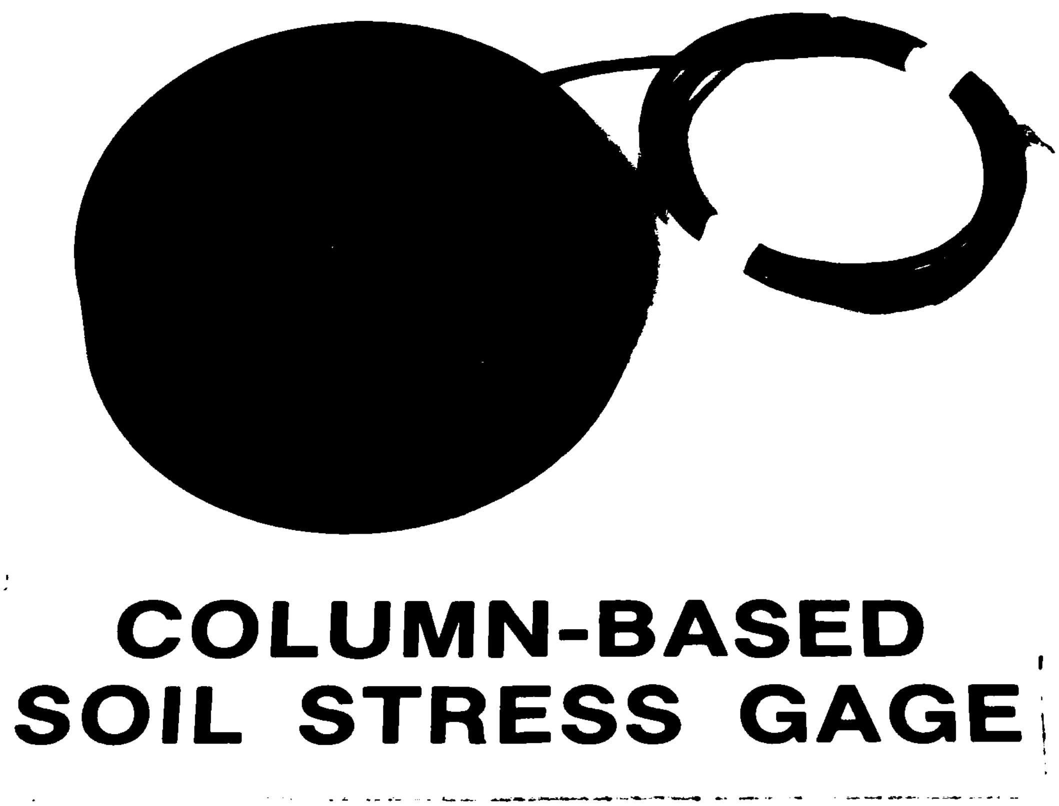
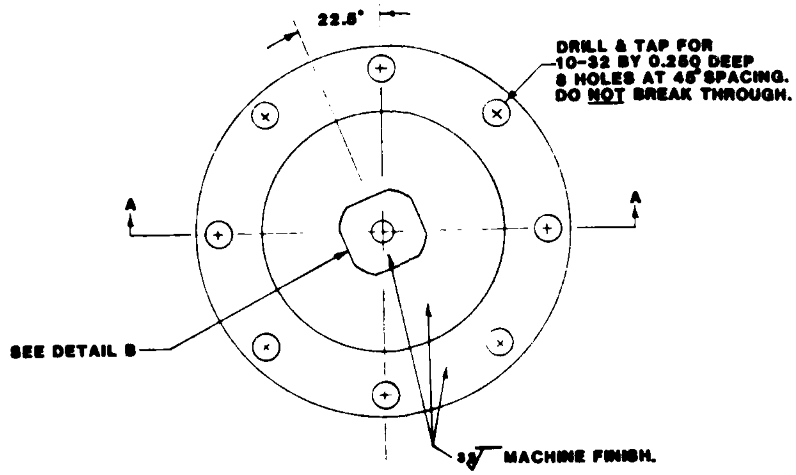


Figure 6. Completed WES CBS gage

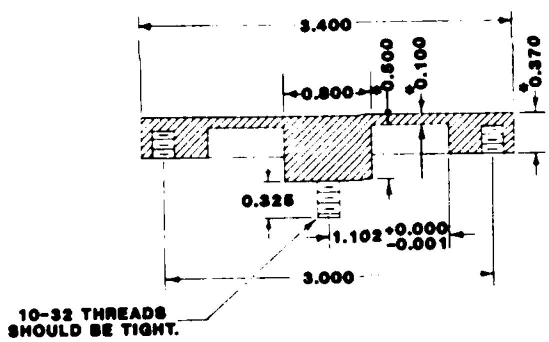
APPENDIX A: MACHINE DRAWING OF WES COLUMN-BASED SOIL STRESS GAGE

~~(A full-size drawing is in an envelope attached inside the back cover of this report.)~~

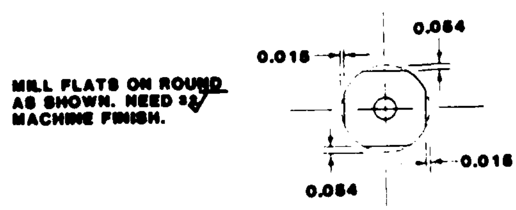
WES COLUMN-BASED SOIL STRESS GAGE



GAGE SENSING ELEMENT
TOP VIEW



SECTION A-A

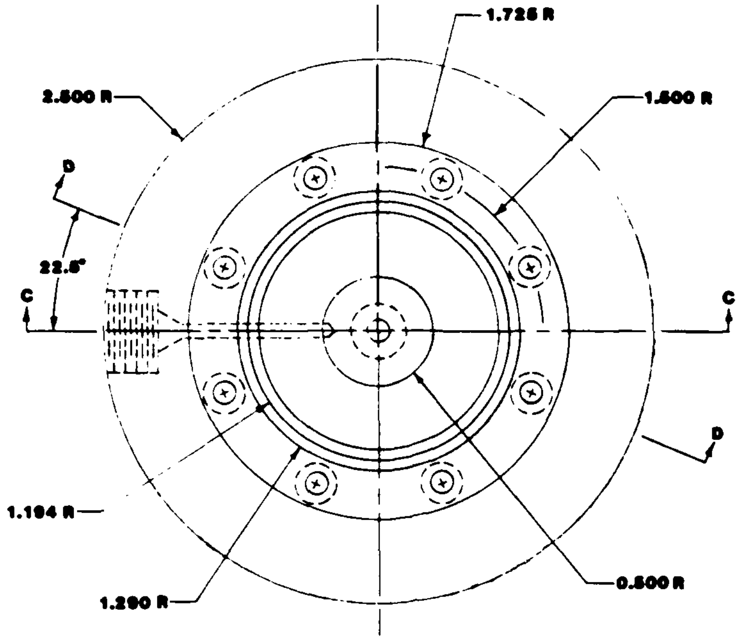


DETAIL B

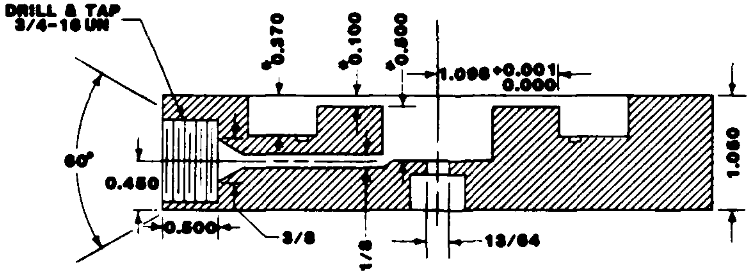
NOTES

1) ALL DIMENSIONS HAVE UNITS OF INCHES.
2) * INDICATES CRITICAL DIMENSIONS, HOLD TO ±0.001. ALL OTHER DIMENSIONS TO BE ±0.003 UNLESS OTHERWISE SPECIFIED.
3) MATING SURFACES TO HAVE 32 MACHINE FINISH.
4) FLATS ON COLUMN TO HAVE 32 MACHINE FINISH.

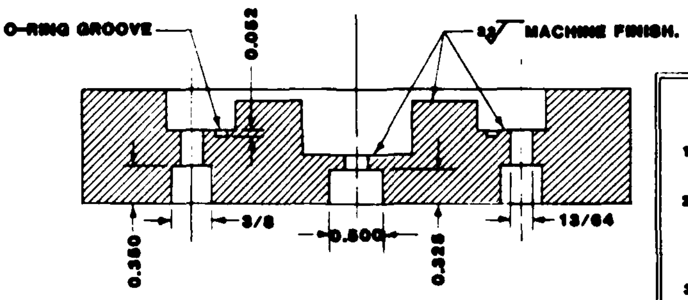
WES COLUMN-BASED SOIL STRESS GAGE



GAGE BODY
TOP VIEW



SECTION C-C



SECTION D-D

NOTES

1) ALL DIMENSIONS HAVE UNITS OF INCHES.
2) * INDICATES CRITICAL DIMENSIONS, HOLD TO ±0.001. ALL OTHER DIMENSIONS TO BE ±0.003 UNLESS OTHERWISE SPECIFIED.
3) MATING SURFACES TO HAVE [illegible]$\sqrt{\ }$ MACHINE FINISH.
4) FLATS ON COLUMN TO HAVE [illegible]$\sqrt{\ }$ MACHINE FINISH.

APPENDIX B: RECOMMENDED SURFACE PREPARATION PROCEDURES FOR INSTALLING STRAIN GAGES WITH EPOXY ADHESIVES*

Step 1. The initial step is to thoroughly degrease the surface with solvents such as Freon TF. Any degreasing should be done with clean solvents and the use of a "one-way" container, such as the aerosol can, is highly recommended.

Step 2. Dry lap the gaging area with 220- or 320-grit silicon-carbide paper to remove any scale or oxides. Highly polished surfaces may require some roughing-up with 320-grit paper to allow proper bonding. Apply a conditioning agent (such as M-PREP CONDITIONER A†) and wet-lap the gage area, keeping the surface wet while lapping. Remove the residue and conditioner by slowly wiping through the gaging area with a gauze sponge. The wet-lap and wiping procedure should be repeated with 400-grit silicon-carbide paper. With a 4H (hard) drafting pencil on aluminum or a ball point pen on steel, burnish whatever alignment marks are needed on the specimen. Rewet the surface with conditioner and scrub with cotton tipped applicators until a clean applicator is no longer discolored by scrubbing. Remove the residue and conditioner, slowly wiping through the gaging area with a gauze sponge.

Step 3. Apply a liberal amount of neutralizing agent (such as M-Prep Neutralizer 5††) to the gage area. Keeping the surface wet, rub with cotton-tipped applicators. Do not allow evaporation of the cleaning agent on the specimen surface since this would leave a thin, unwanted film between the adhesive and the

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* This appendix quoted from data supplied by Measurements Group, Inc., Raleigh, NC.

† Trademark of Micro-Measurements, Measurements Group, Inc.

†† Trademark of Micro-Measurements, Measurements Group, Inc.

specimen. Remove the neutralizer by slowly wiping through the gage area, allowing the gauze sponge to absorb the neutralizer. Do not wipe back and forth over the gage area, since this may allow contaminants to be redeposited on the cleaned area.

Step 4. Remove the strain gage from the acetate envelope by grasping the edge of the gage backing with clean tweezers, and place on a chemically clean glass plate or empty gage box with the bonding side of the gage down. If a solder terminal is to be incorporated, position it on the plate, adjacent to the gage. A space of approximately 1/16 in. should be left between the gage backing and terminal. Use Mylar tape to position the gage, and wipe forward onto the gage. Carefully lift the tape at a shallow angle (approximately 45° to specimen surface), bringing the gage up with it.

Step 5. Position the gage/tape assembly so the triangle alignment marks on the gage are over the layout lines on the specimen. Holding the tape at a shallow angle, wipe the assembly onto the specimen surface. If the assembly appears to be misaligned, lift one end of the tape at a shallow angle until the assembly is free of the specimen. Realign properly and firmly anchor down at least one end of the tape to the specimen. This alignment can be done without fear of contamination by the tape mastic if the recommended cellophane tape is used. This tape will retain the mastic when removed.

Step 6. Lift one end of the tape at a shallow angle to surface (about 45°) until gage is free of specimen surface. Tuck loose end of tape under and press to surface so the gage lies flat with the bonding side exposed.

Step 7. Coat specimen and back of gage with the prepared adhesive over both surfaces. Be careful not to pick up any unmixed components of the adhesive. To ensure this, it is advisable to use adhesive from the center of the adhesive jar. Immediately after coating the gage and specimen with adhesive, proceed to Step 8. This will limit absorption of moisture by the uncured adhesive.

Step 8. Lift tucked-over end of tape and bridge over adhesive at approximately a 30° angle. With a piece of gauze, slowly make a single wiping stroke over the gage/tape assembly, bringing the gage back down over the alignment marks on the specimen. Use firm pressure when wiping over the gage, since the adhesive is quite viscous. A very thin layer of adhesive is required for optimum bond performance.

Step 9. Place a silicone gum pad and backup plate over the gage installation. The silicone gum should be soft (Durometer A40-60) and at least 3/32 in. thick. This will allow the clamping force to be exerted evenly over the gage.

Step 10. Apply force by spring clamp or dead weight until a clamping pressure of 5 to 20 psi is attained. Take special care in making sure the clamping pressure is equal over the entire gage. Unequal clamping pressure may result in an irregular glue line. Take steps to ensure that the clamps will not slide out of position during cure.

END

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